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Prediction of Compression of Knitted Orthopaedic Supports by Inlay-Yarn Properties

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The aim of this study was to find out the possibility to predict the compression properties of orthopaedic knits by inlay-yarn properties. For this purpose, six groups of elastic double covered threads with different raw material were investigated. It was established that in area of low elongation, the covering threads practically don't have significant influence on tensile force values. Also results demonstrate that by increasing the number of tested threads, the elongation value has a higher impact on tensile force. The influence of linear density of elastic PU core on tensile force increases by increasing elongation value of threads. When influence of inlay-yarn linear density and number of threads on tensile force is determined it is possible to predict influence of inlay-yarn properties on compression properties of knitted orthopaedic supports.

Keywords: inlay-yarn, linear density, tensile behaviour, compression.

1. INTRODUCTION

Compression garments are special products that exert a pressure on the patient's body. They can be used in two main areas: medical, which includes different sub-sectors such as orthopaedics, aesthetics, among others, and sports involving different modalities.

Elastic threads for medical textiles are generally used for non-implantable materials for external applications on the body and for compression therapy. Compression therapy is the deliberate application of pressure to a limb in order to prevent and treat disease of venous or lymphatic systems [1]. Due to different requirements not covered bare elastane is not used in the textile structure. Generally it is covered with other raw materials, which are chosen according to the end use. The inlay-yarns is a synthetic elastic thread with textile filaments wrapped around it, this is called covered yarn [1 – 4].

The fabric used to make compression garments is produced by knitting two different threads systems: ground thread ensures the thickness and stiffness to knitted fabric and inlay-yarn generates the compression. As previously mentioned, the inlay-yarns are produced by wrapping polyamide or cotton around a stretchable core such as latex or polyurethane. The wrapping can be adjusted to vary the tensility and strength of the thread. Tensility is a measure of elongation of thread by stretching. High power thread is less easy to stretch and thus applies greater compression [4]. Polyurethane (PU) thread can be inlayed, floated or plated in the knitted structure. The thickness, texture and appearance of the knitted fabric also can be changed by adapting the wrapping of the thread. Higher levels of compression are mainly achieved by increasing the thickness of the elastic core of inlay-yarn, although adjustments may also be made to the ground yarn [4].

The weft inlay-yarns can be introduced in each course or in certain courses, according to a pattern. The presence of these yarns increases the fabric strength and fabric compactness. Such structures with elastomeric inserted threads are used for the stockings welt and for medical products – orthopaedic stockings and supports. Comandar [5] investigated structural variants where the elasticity along the course direction is controlled through the weft yarn insertion. It was found that the weft inlay-yarn influences the fabric extensibility in both (longitudinal and transverse) directions.

Mechanical behaviour of the covered yarn, which is the main yarn component of the elastic knitted fabric of the medical compression stockings, was investigated by several authors. The structure analysis shows that properties of the inlaid yarns reflect significantly the global behaviour of the fabric. Therefore, by characterizing the elastic properties of the inlay-yarn, it is possible to predict the mechanical behaviour of the entire medical compression fabrics [6 – 8].

There is limited literature on properties of elastic covered yarns (with different covering yarn raw material) used for medical application. Usually the dimensional and physical properties of core-spun cotton/spandex yarns are investigated. Several studies were carried out to investigate the properties of core-spun cotton/spandex yarns used in single jersey [9, 10], in interlock [11], in rib knitted structures [12].

The physical properties of weft knitted fabrics for compressive functional behavior are influenced by different factors: the material – type and linear density of yarn, the knitting structure – pattern and elastic inlay-yarn insertion density, and the productions process – machinery and specific parameters of production [13]. The main compression load in knitted support is generated by elastic thread. Therefore, the properties of covered elastic thread – linear density of rubber (i. e. core part of elastic thread) and twist amount of covering thread – are very important for the compressive properties of knitted supports.

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The aim of this study was to find out the possibility to predict the compression properties of orthopaedic knits by inlay-yarn properties.

2. EXPERIMENTAL

In this study, six different types of elastic covered thread samples were tested. Their characteristics are presented in Table 1. All selected threads were divided into separate groups according to raw material: 1) P group – polyurethane (PU) threads double covered with polyamide 6.6 (PA 6.6) threads; 2) PM group – PU threads double covered with PA 6.6 and cotton or viscose threads; 3) M group – PU threads double covered with cotton threads.

Table 1. Characteristics of tested elastic double covered threads

Thread code	Composition of elastic covered thread		Total linear density of thread, tex
	Elastic core – polyurethane (PU), linear density (tex)	Raw material and linear density of covering thread	
P2	47	PA 6.6, 2.2 tex and PA 6.6, 2.2 tex	55
P3	132	PA 6.6, 16 tex and PA 6.6, 16 tex	230
PM2	233	PA 6.6, 11 tex and viscose 14.3 tex	340
PM3	240	PA 6.6, 28 tex and cotton, 25 tex	350
M1	33	Cotton, 8.5 tex and cotton, 8.5 tex	95
M2	554	Cotton, 18.5 tex × 3 and cotton, 18.5 tex	720

The tensile properties of tested threads were measured using universal testing machine ZWICK/Z005 according to the LST EN ISO 2062:2010 standard. The gauge length of tested yarns was 250 mm, due to their high elasticity. Constant rate of displacement of the moving clamps was 250 mm/min. The tensile properties of threads were performed until medium elasticity because in orthopaedic supports elastic inlay-yarn undergoes extension values very distant to breaking. Tensile tests with 50 %, 100 %, 150 %, 200 %, 230 % fixed extension were executed.

The inlay-yarn is inserted into structure of orthopaedic supports relative straight. Therefore, the extensibility of threads can be tested individually, not in the knitted structure. The samples have been stretched in five different variants (1 thread, 2 threads, 3 threads, 4 threads and 5 threads) to investigate the influence of inlay-yarns number on tensile properties.

The total linear density of elastomeric yarns was measured according to D 2591-01 standard.

The calculated relative error values of tensile force didn't exceed 5 %.

3. RESULTS AND DISCUSSION

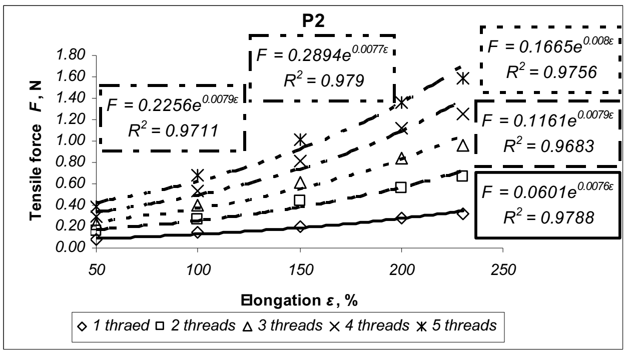
The compression determined by orthopedic supports is strongly related to the elastic thread properties and the technique employed to knit the thread into the final product. Whereas the main compression load in knitted support is generated by elastic inlay-yarn, it is important to know the behavior of such threads. The dependencies of investigated threads tensile force value on elongation during stretching and number of threads are presented in Figs. 1 – 3.

The results show that tensile force exponentially depends on elongation value (in all cases the coefficient of determination R^2 ranged from 0.9571 till 0.9996). It means that by increasing elongation value the tensile force exponentially increases.

The results demonstrate that by increasing the number of tested threads, the elongation value has a higher impact on tensile force. The compression level is directly in relation with pressure P [7]. The physical definition of pressure is :

$$P = 2\pi F/S, \quad (1)$$

where F is the limb pressure force in N; S is the product area in m^2 [14]. Thus, the higher tensile force occurs when knit is stretched, this force affects compression properties, i. e. growth of the tensile force increases compression of knitted orthopaedic support. Therefore, in area of low elongations (50 %), the difference of tensile force between 1 and 2 threads is approximately 2 times, while between 1 and 5 threads approximately 5 times. The same tendency was observed for the threads that were stretched at 100 and 150 % extension. However, in area of even higher elongation (230 %) the difference of tensile force between 1 and 2 threads is approximately 1.9 times, while between 1 and 5 threads approximately 4.5 times. The exponential dependence is an indication that there is still an increase in elongation and this difference would increase even more significantly.



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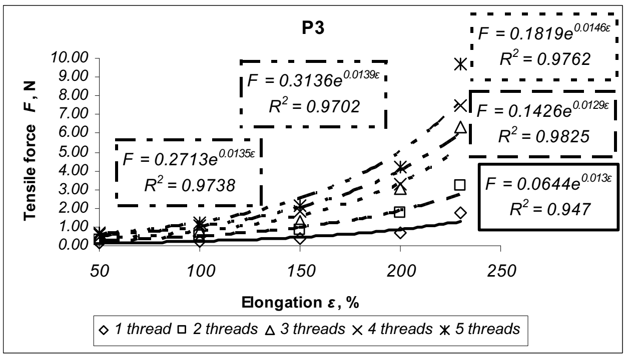

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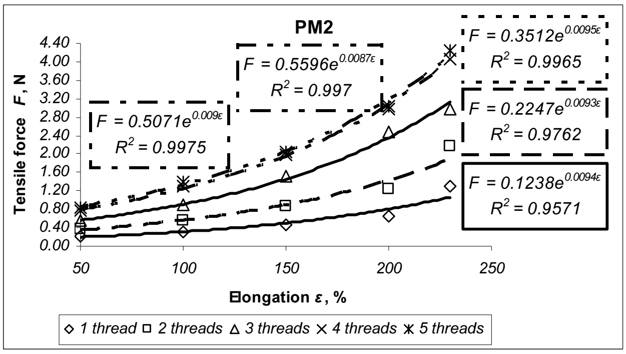
Fig. 1. Dependence of tensile force value on elongation during stretching and number of threads: a, b – PU threads double covered with PA 6.6 threads



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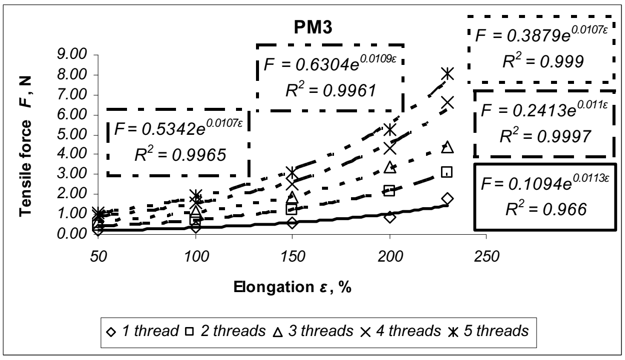

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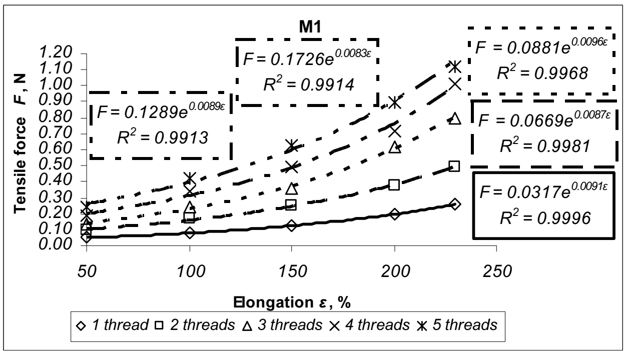
Fig. 2. Dependence of tensile force value on elongation during stretching and number of threads: a, b, – PU threads double covered with PA 6.6 and viscose or cotton yarns



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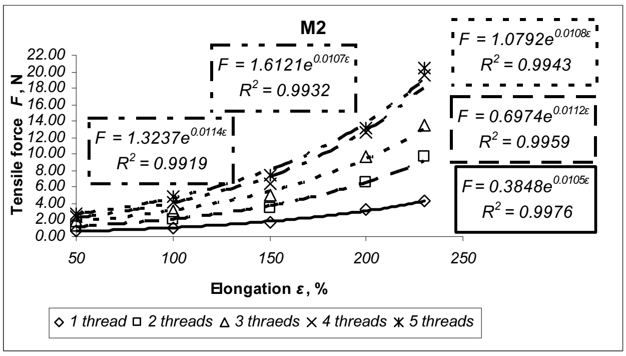


b

Fig. 3. Dependence of tensile force value on elongation during stretching and number of threads: a, b, – PU threads double covered with cotton yarns

Orthopedic knitwear sustain low elongation during exploitation. In the area of low elongations, the inlay-yarn is stretched so that only elastomeric core is affected by tensile force. The covering threads practically don't have significant influence on tensile force values. The same tendency was found by other researchers [15]. Therefore, compression are generated by elasticity and extensibility of elastomeric (PU) core and covering threads only important for aesthetic and hygienic properties. For this reason, investigation of the influence of linear density only of PU core threads on tensile force value was carried out and results are presented in Fig. 4.

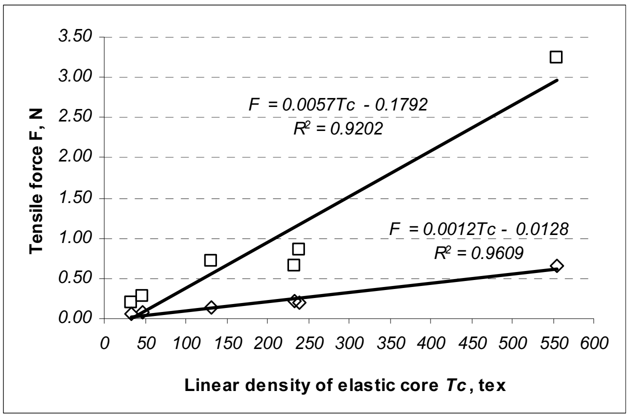
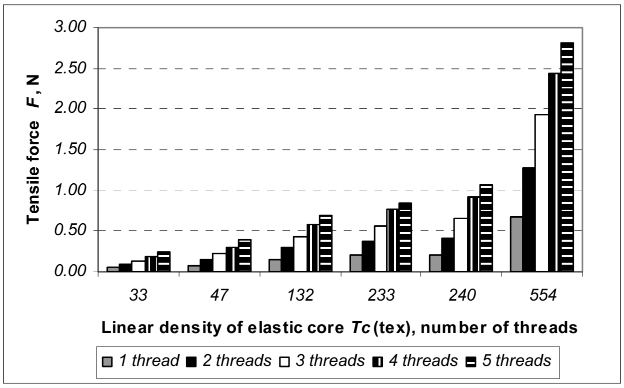


Fig. 4. Dependence of tensile force value on linear density of PU core threads during stretching (◇ – 1 thread, 50 % of extension, □ – 1 thread , 200 % of extension)

The results presented in Fig. 4 demonstrate that tensile force linear depends on linear density of elastomeric PU core. By increasing linear density of PU, core tensile force increases also. However, the results presented in this figure show another important issue. The influence of linear density of elastic PU core on tensile force increases by increasing elongation value of threads. In area of low elongation (50 %), the tensile force increases approximately 13 times when the linear density of PU core thread increases approximately 18 times. Meanwhile, in the area of higher elongations (200 %), the tensile force increases approximately 18 times when the linear density of PU core thread increases approximately 18 times. Thus, in the case of the increase in elongation values and linear density of PU core, the resistance to stretching (i. e. tensile force) also increases. It means that increasing tensile force and number of threads generate higher compressive force of orthopaedic support. This statement was comfirmed by other authors as well [16].

The detailed influence of linear density of PU core, number of threads and elongation value on tensile force values are presented in histograms of Fig. 5. The tensile force values at 50 % of extension are presented in Fig. 5, a. When linear density of PU core thread are relatively low (for example 33 tex) the influence of threads number on tensile force distributes proportionally. It means when the number of threads increases twice then tensile force increases twice as well. When number of threads increases five times the tensile force increases by about 4.9 times.



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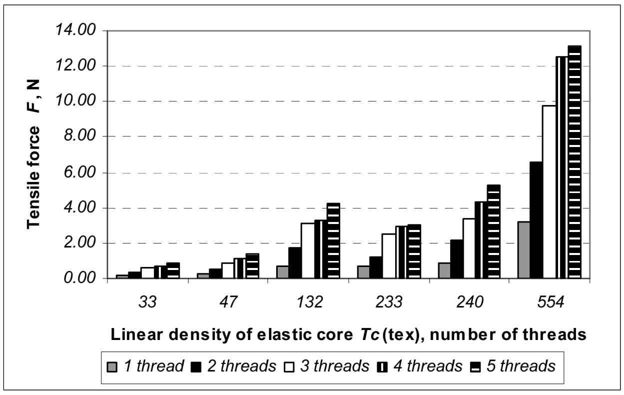

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Fig. 5. Dependence of tensile force value on linear density of PU threads and number of threads during stretching: a – when threads were stretched at 50 %; b – when threads were stretched at 200 %

However the influence of threads number on tensile force changes when linear density of PU core threads increases (for example at 233 tex or even 554 tex). Thus when number of threads increases twice the tensile force increases approximately 1.9 times, and when number of threads increases 5 times tensile force value increases only approximately 4 times. The similar tendency was observed for threads that were stretched at 200 % extension (Fig. 5, b).

These investigations prove the influence of inlay-yarn properties on tensile force value and compression of laid-in knit as well, and they will be continued in the future.

4. CONCLUSIONS

The dependence of tensile force on elongation and number of threads has an exponential character. It means that by increasing elongation value, the tensile force exponentially increases. By increasing the number of tested threads, the elongation value has a higher impact on tensile force.

When influence of inlay-yarn linear density and number of threads on tensile force is determined, it is possible to predict influence of inlay-yarn properties on compression properties of laid-in knitted orthopaedic supports. In area of low elongations, influence of the linear density of elastic PU thread is not significant. It means the lower amount of inlay-yarn can be laid in knitted support and economical effect can be achieved.

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